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Systematic Study of Quasifission in ^{48}Ca-induced reactions

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Abstract. The production of superheavy elements through the fusion of two heavy nuclei is severely hindered by the quasifission process, which results in the fission of heavy systems before an equilibrated compound nucleus (CN) can be formed. The heaviest elements have been synthesised using ^{48}Ca as the projectile nucleus. However, the use of ^{48}Ca in the formation of new superheavy elements has been exhausted, thus a detailed understanding of the properties that made ^{48}Ca so successful is required. Measurements of mass-angle distributions allow fission fragment mass distribution widths to be determined. The effect of the orientation of prolate deformed target nuclei is presented. Closed shells in the entrance channel are also shown to be more important than the stability of the formed CN in reducing the quasifission component, with reduced mass widths for reactions with the closed shell target nuclei ^{144}Sm and ^{208}Pb. Comparison to mass widths for ^{48}Ti-induced reactions show a significant increase in the mass width compared to ^{48}Ca-induced reactions, highlighting the difficulty faced in forming new superheavy elements using projectiles with higher atomic number than ^{48}Ca.

1 Introduction

Superheavy elements (SHEs) mark the upper boundary of the existence of atomic nuclei. Their production offers an insight into exotic nuclear structure, and provides thorough tests of established nuclear models. Oganesson ($^{294}_{118}$Og) represents the heaviest element synthesised to date, produced in the ^{48}Ca + ^{249}Cf reaction [1, 2]. For a SHE to be produced, two heavy nuclei must come into contact and form an equilibrated compound nucleus (CN), by evolving from the di-nuclear shape at contact, to that of a compact system [3, 4]. Due to the large repulsive Coulomb force, the system often instead breaks apart before this equilibrated system is reached. This process is known as quasifission (QF) [5–7]. This significantly suppresses the yield of desired products, and can be the most significant hindrance to SHE formation.

The difficulty in forming SHEs is further compounded by the need for heavier projectile nuclei than ^{48}Ca, as production of targets of elements heavier than Cf is currently not achievable. ^{48}Ca has been successfully used in SHE formation reactions, due in part to its high N/Z ratio and doubly magic shell structure [8, 9]. However, to form elements 119 or larger, heavier projectiles must be used, which should have similar properties to ^{48}Ca. The most favourable projectiles are expected to be ^{50}Ti and ^{54}Cr, however neither of these are doubly magic, nor as neutron-rich as ^{48}Ca [9]. A recent study [10] highlighted that the lack of these key characteristics of ^{48}Ca in both ^{50}Ti and ^{54}Cr leads to a significant reduction in the probability of forming an equilibrated CN.

There has been a surge in experimental and theoretical investigations of quasifission in recent years. The complex dynamics has many different dependencies, with experiments highlighting the influence of entrance channel properties such as nuclear deformation and orientation [11–16], mass asymmetry [3, 5, 17, 18], magicity [19, 20] and shell structure [21–24]. The multiple parameters that have significant effects on fusion cross sections serve to highlight the complexity of the dynamics, and the challenge that is posed to produce a model that can account for all of these effects.

A systematic study of ^{48}Ca-induced reactions with a variety of target nuclei at energies close to the Coulomb barrier is presented. Mass-angle distributions (MADs) were measured, and fission fragment mass distribution widths were determined. The targets used in this work range from the spherical ^{144}Sm, to strongly deformed nuclei, such as ^{170}Er and ^{186}W, through to the spherical ^{208}Pb. These targets allow the investigation of the role of deformation in this work. Moreover, the role of closed shells is demonstrated due to the fact that the ^{48}Ca projectile and ^{208}Pb target both have full proton and neutron shells, whilst ^{144}Sm has a closed neutron shell.

2 Mass-Angle Distributions and Mass Widths

MADs show the distribution of fission fragment masses as a function of centre-of-mass scattering angle, $\theta_{c.m.}$. This

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